GRANT:2017/05685-2

A hybrid model for simulating Heavy-Ion Collisions

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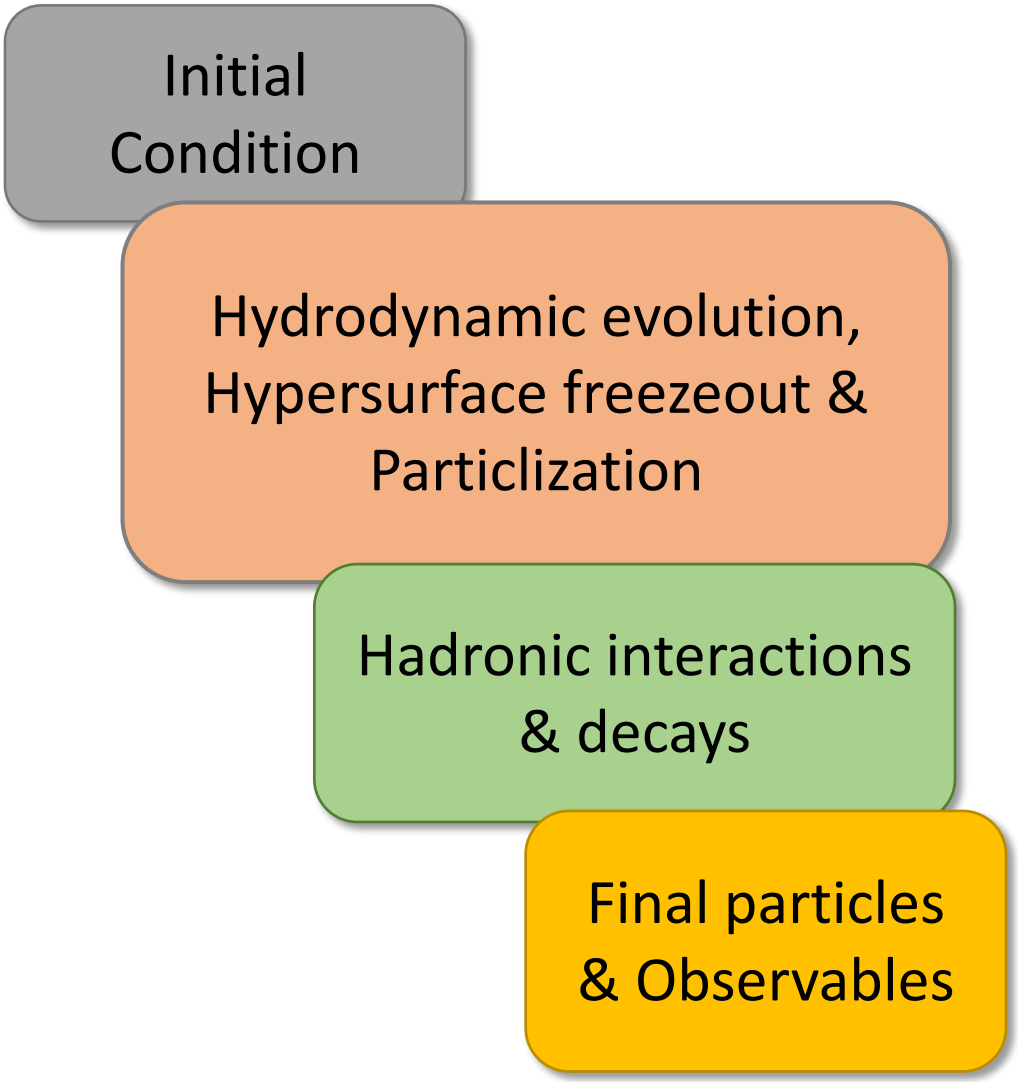
Hybrid Model

TRENTo + KoMPost

MUSIC + iSS Sampler

UrQMD

Root + Hadrex



Hybrid Model

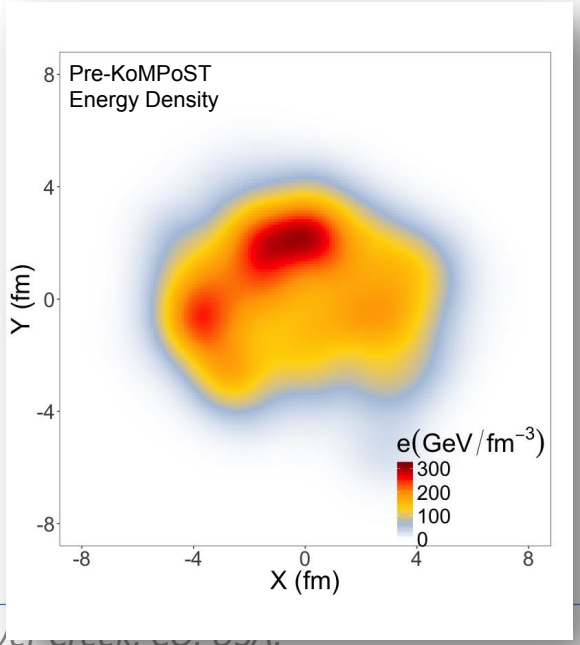
TRENTo + KoMPost

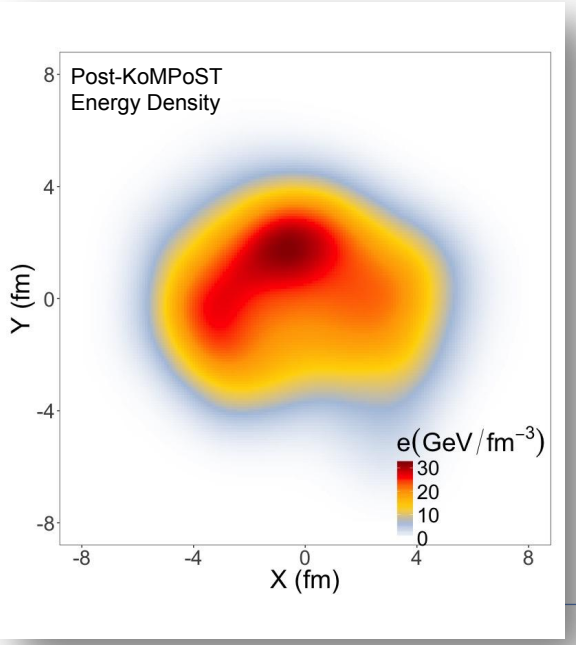
Initial Condition

TRENTo: Generates Energy (entropy) terms of the IC.
http://qcd.phy.duke.edu/trento/

KoMPost: Simulates Pre-equilibrium dynamics with kinetic theory.

https://arxiv.org/abs/1805.00961





Hybrid Model

TRENTo + KoMPost

Initial Condition

MUSIC + iSS Sampler

Hydrodynamic evolution, Hypersurface freezeout & Particlization

MUSIC: 3+1 hydrodynamics for the evolution of the QGP phase.

http://www.physics.mcgill.ca/music/

iSS sampler: thermal production of hadrons from freezeout hypersurface.

https://github.com/chunshen1987/iSS

Hybrid Model

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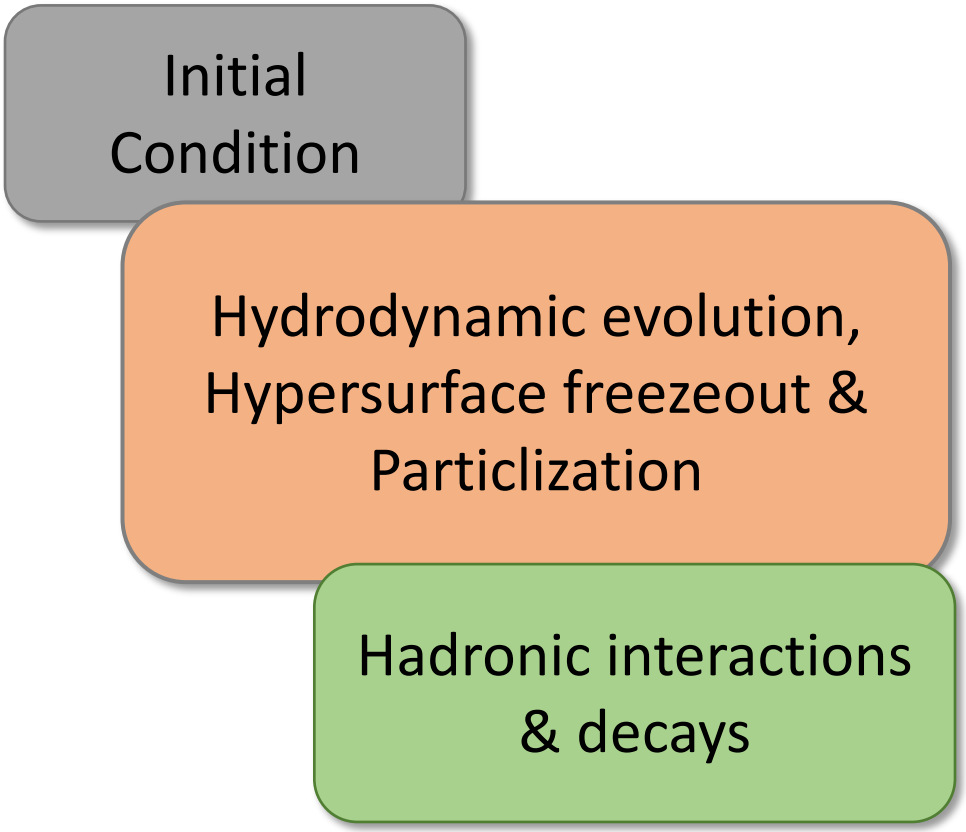
UrQMD



UrQMD: hadronic cascade simulator: dynamics of the system after hadronization and resonance decays.

https://urqmd.org/

Hybrid Model

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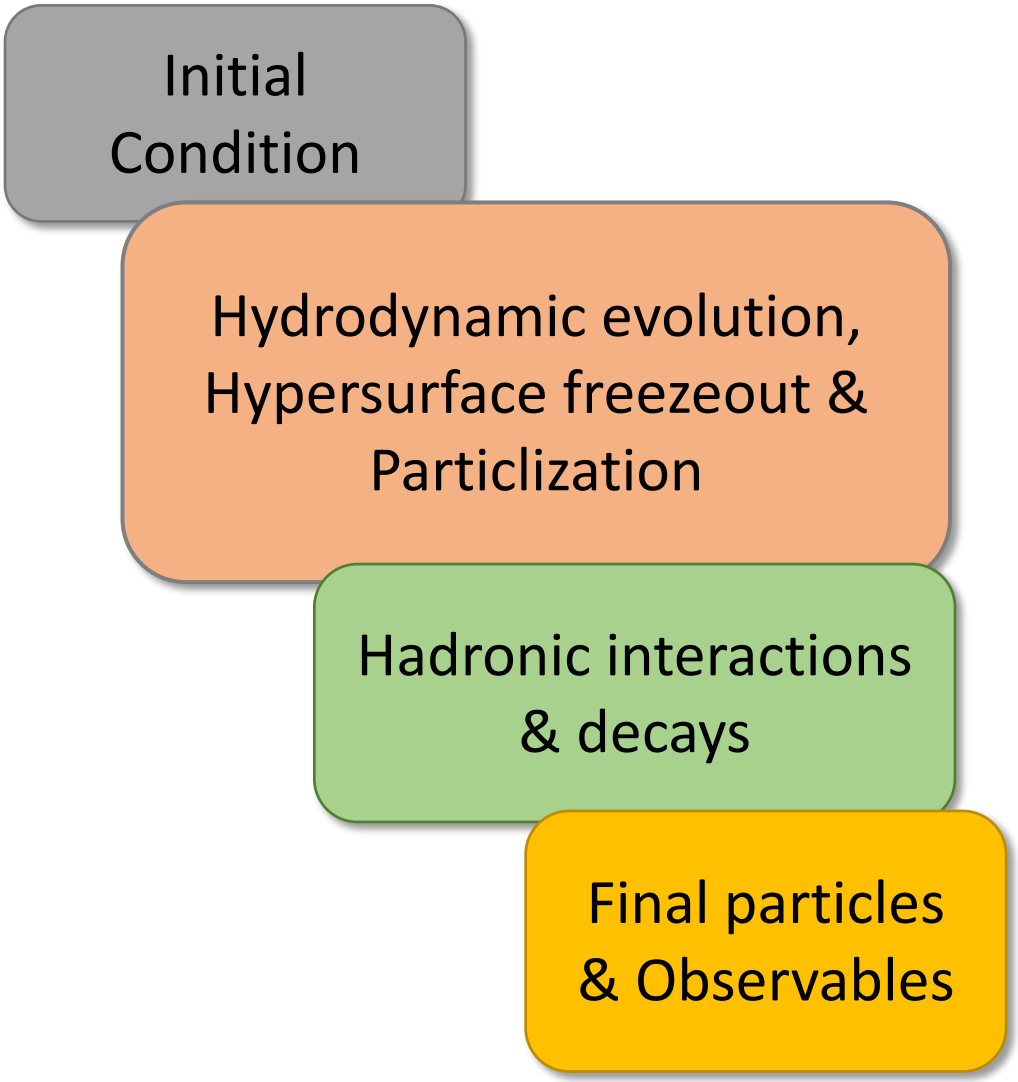
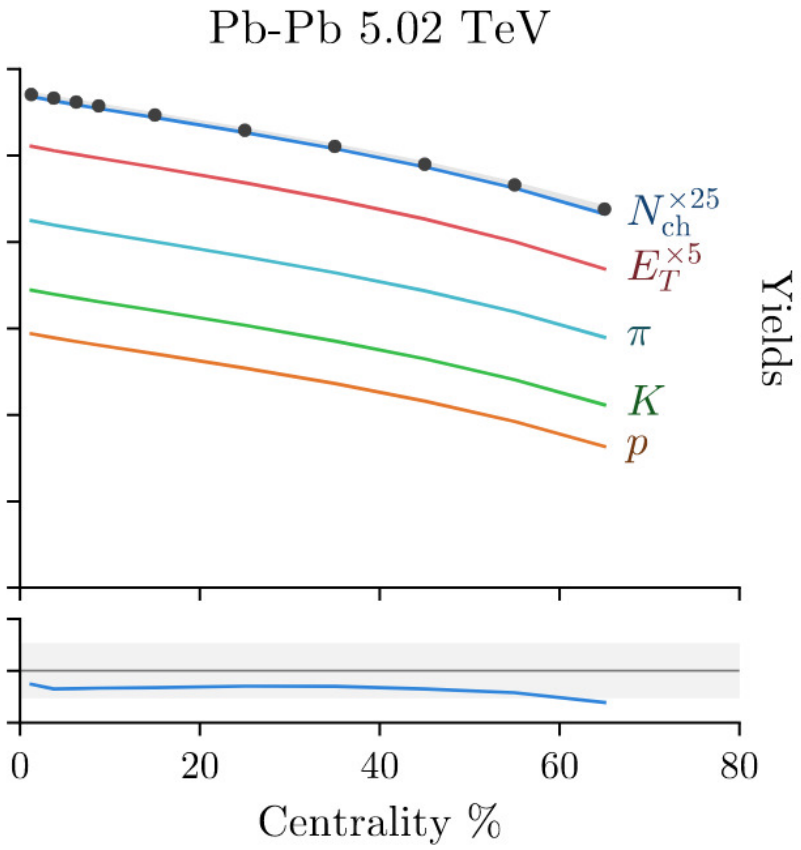


Configuring the Chain



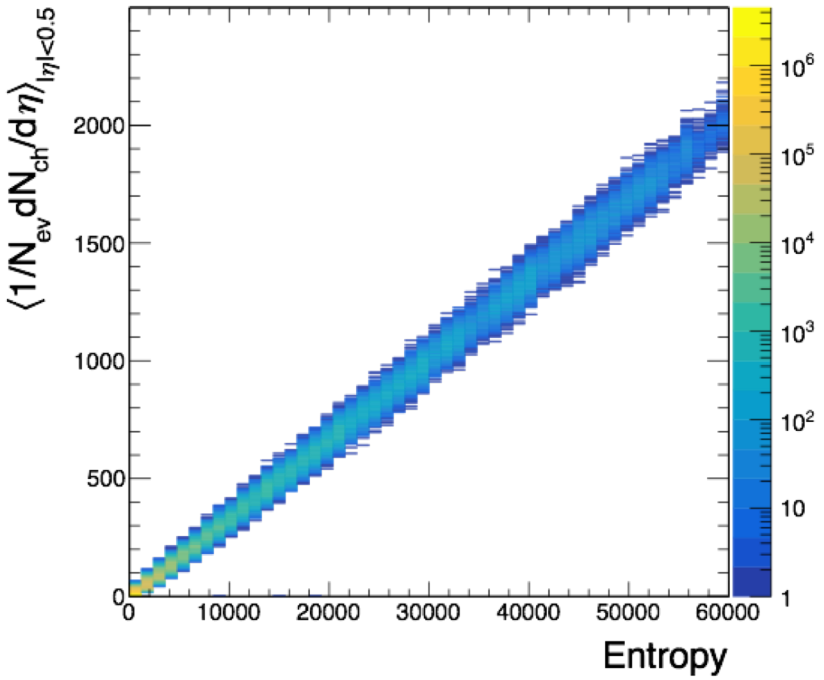
Duke Group data driven parameter optimization using Bayesian analysis [1]:

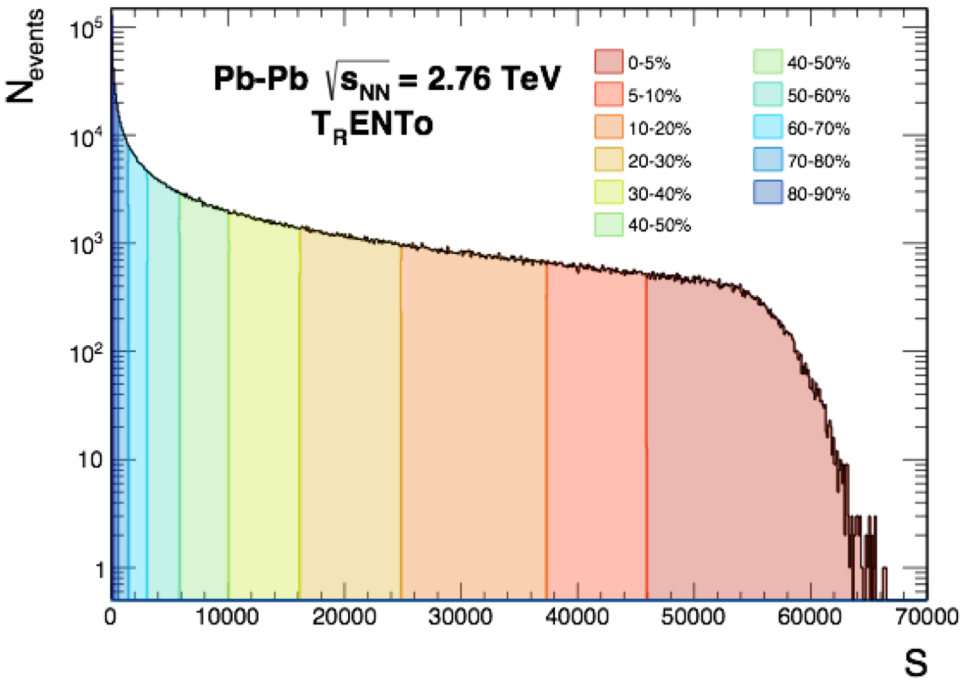
They used a framework similar to ours: TRENTo + Free Streaming + VISH2+1 + FRZOUT + UrQMD

- We utilize these parameters but with a different overall normalization
- Minor differences in the two approaches under study

[1] Nucl. Phys. A, 967 (2017) 67-73.

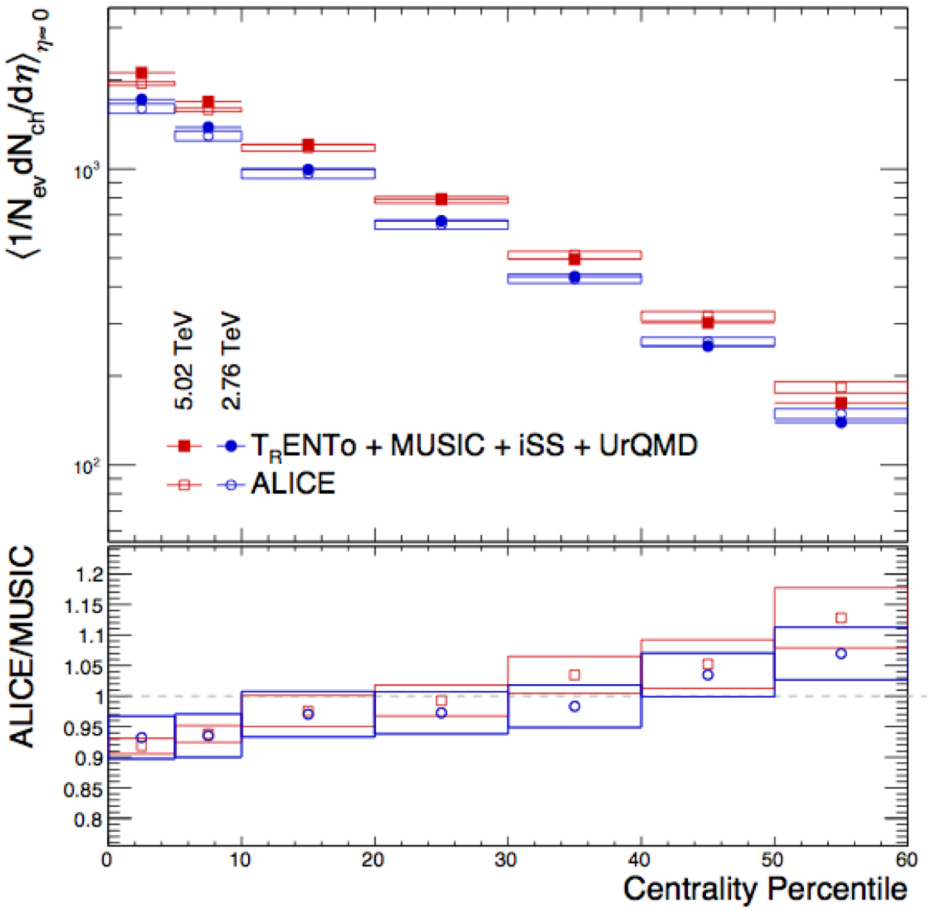
Centrality determination





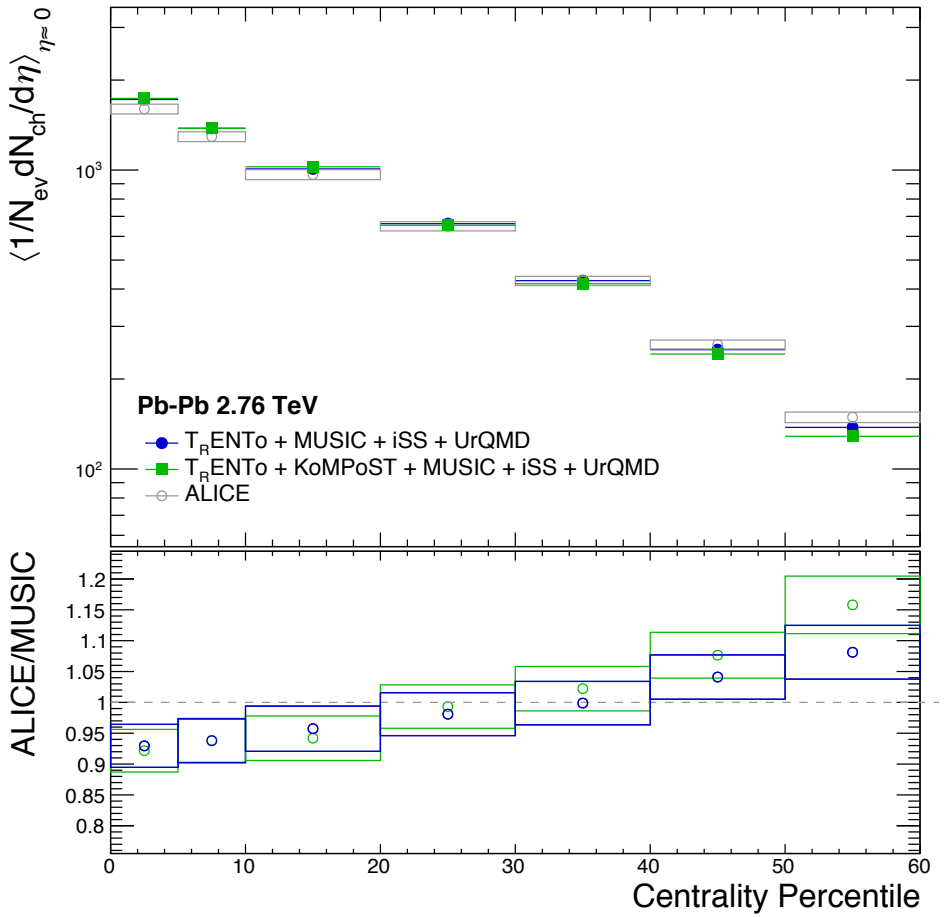
- Strongly correlated: Initial entropy S and final charged-particle multiplicity.
- Centrality calibration based on a sample of 10^6 TRENTo initial conditions and entropy classification.

Charged Particle multiplicity



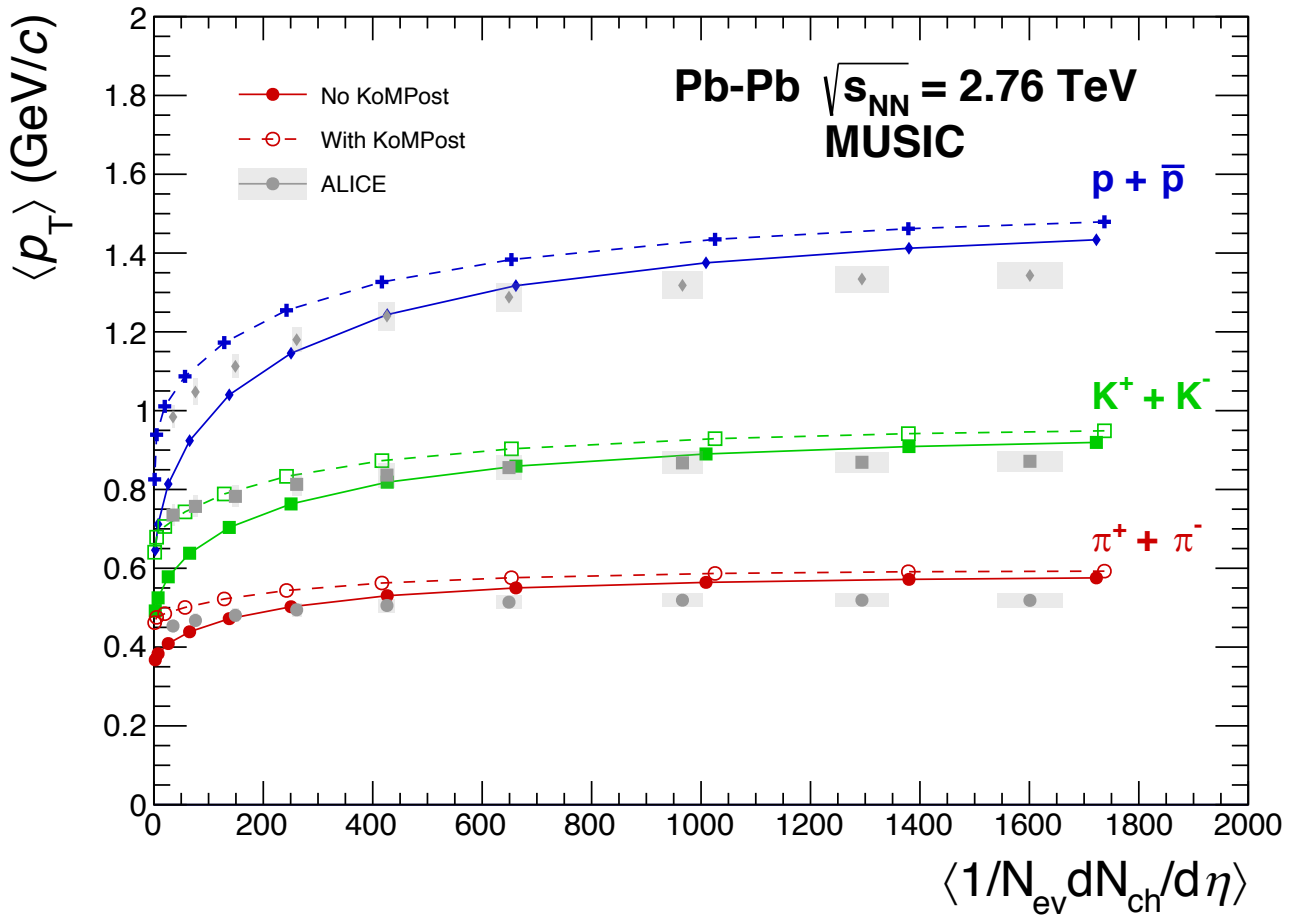
Overall normalization factor adjusted to describe data multiplicity.

Including Pre-equilibrium: KoMPost



Small variation in the multiplicity dependency with collision centrality.

Average Transverse momentum



Slight increase of $\langle p_T \rangle$ with the inclusion of KoMPost. Result will depend on the initialization parameters.

Flow fluctuation with PCA analysis

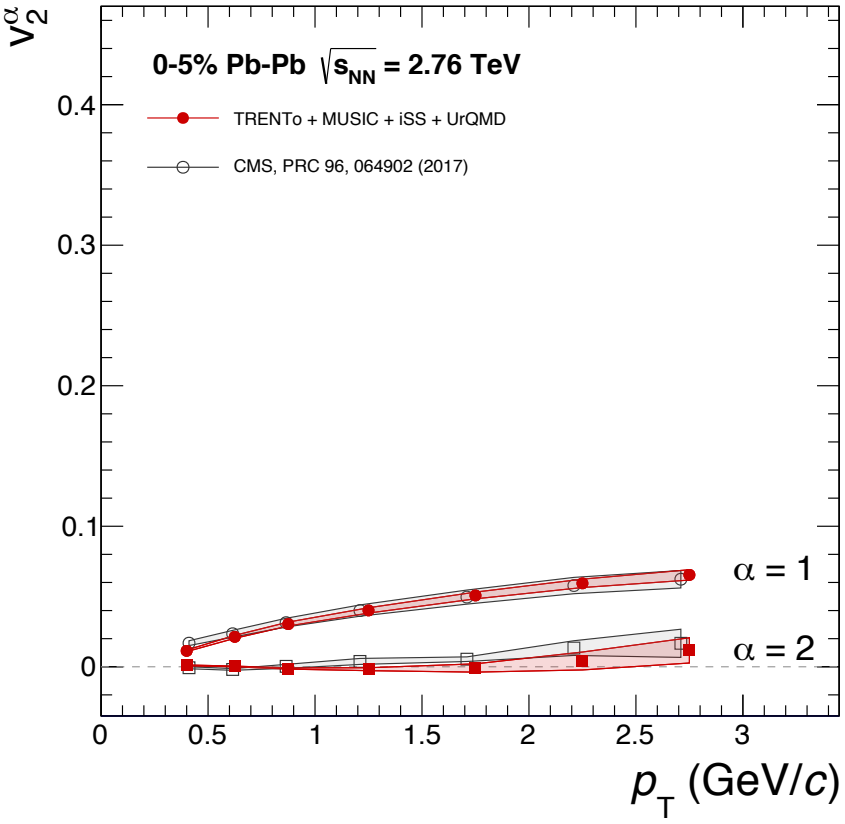
PRL 114 (2015) 152301.
PCA analysis applied to two particle correlation matrix can provide information on flow fluctuations.

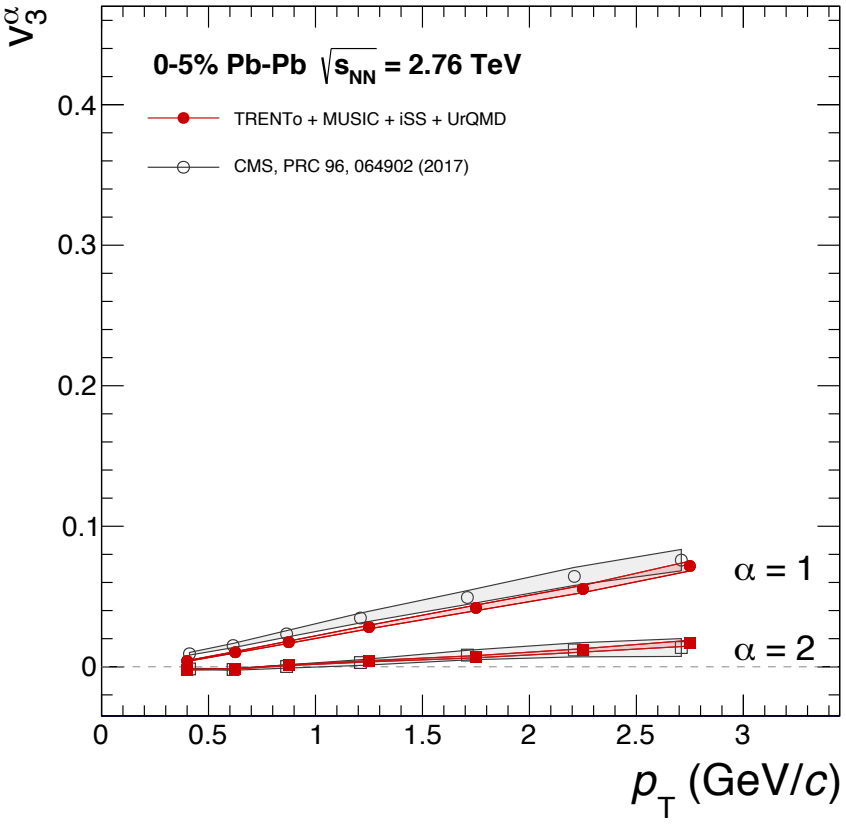
For compatibility with the usual flow picture:

$$v_n^{(\alpha)}(\vec{p}) \equiv \frac{V_n^{(\alpha)}(p)}{V_0(p)}$$

- This way, the $\alpha = 1$ term will be equivalent to v_n measured via the usual two-particle correlation techniques. In the absence of fluctuations, it will correspond to the usual anisotropic flow.
- …and the subleading ($\alpha = 2$) term quantifies factorization breaking in different momentum bins
- More information by exploiting the correlation matrix

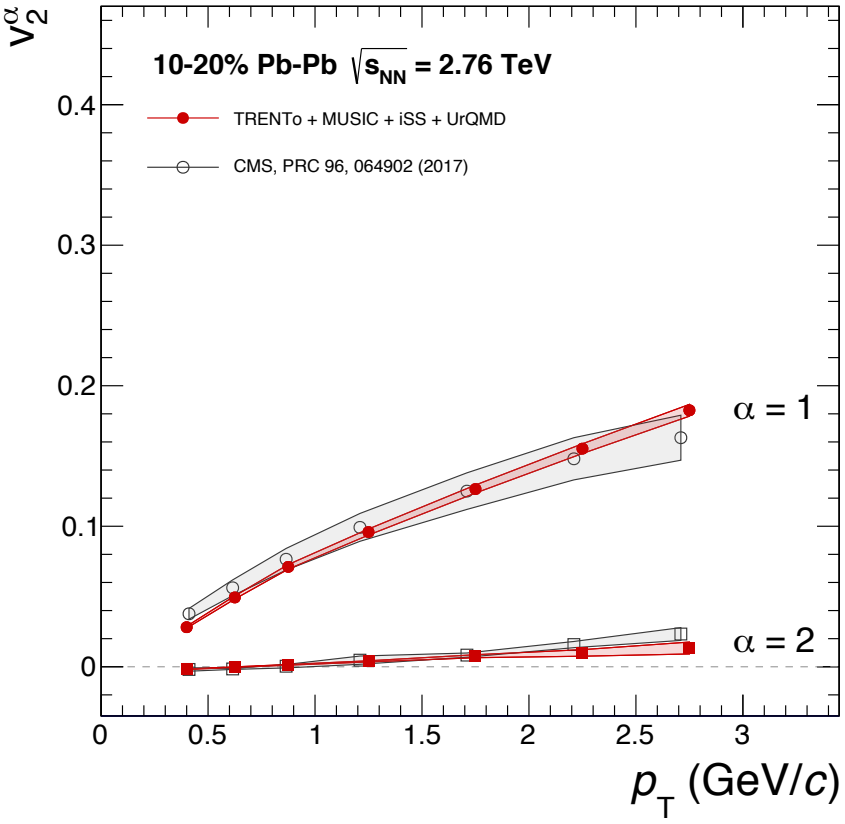
PCA for 0-5% Pb-Pb 2.76 TeV

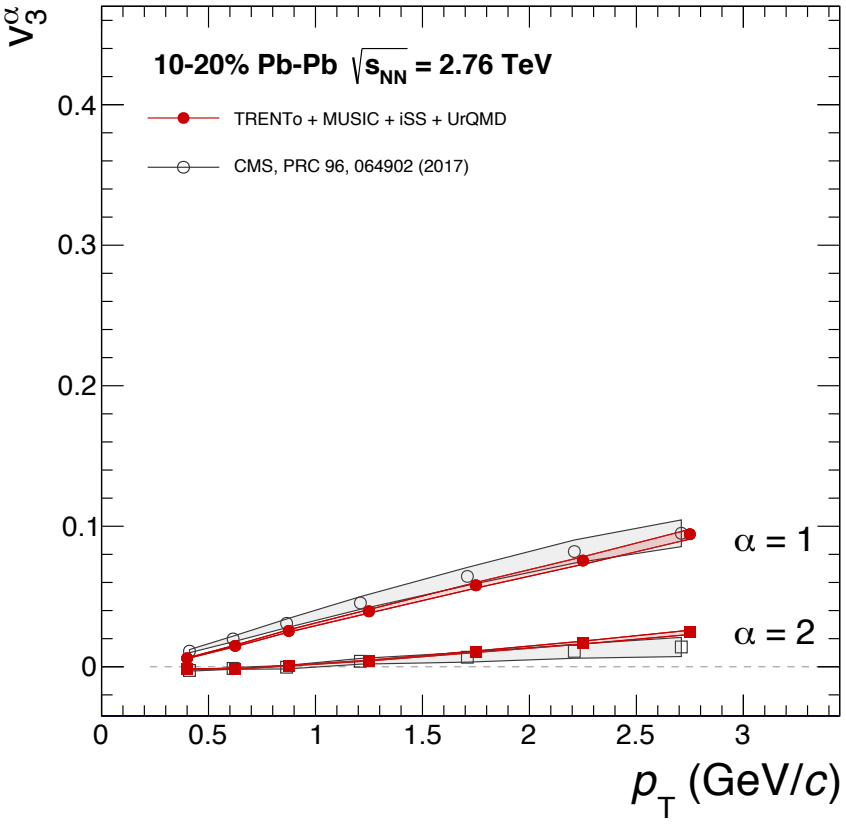




Model describes data within uncertainties for $\alpha = 1, 2$.

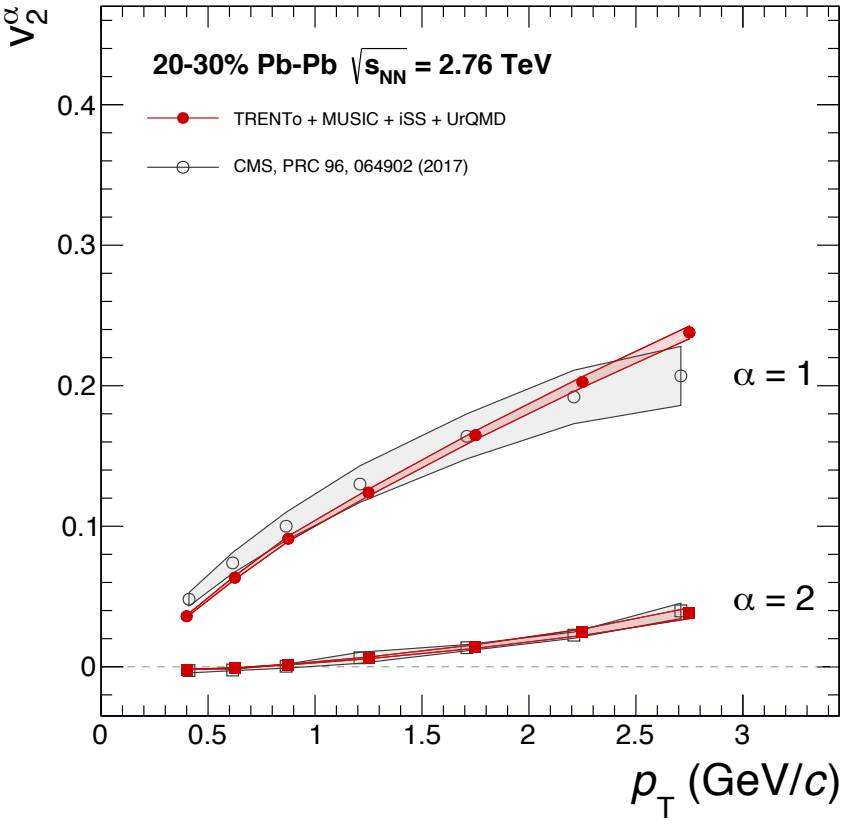
PCA for 10-20% Pb-Pb 2.76 TeV

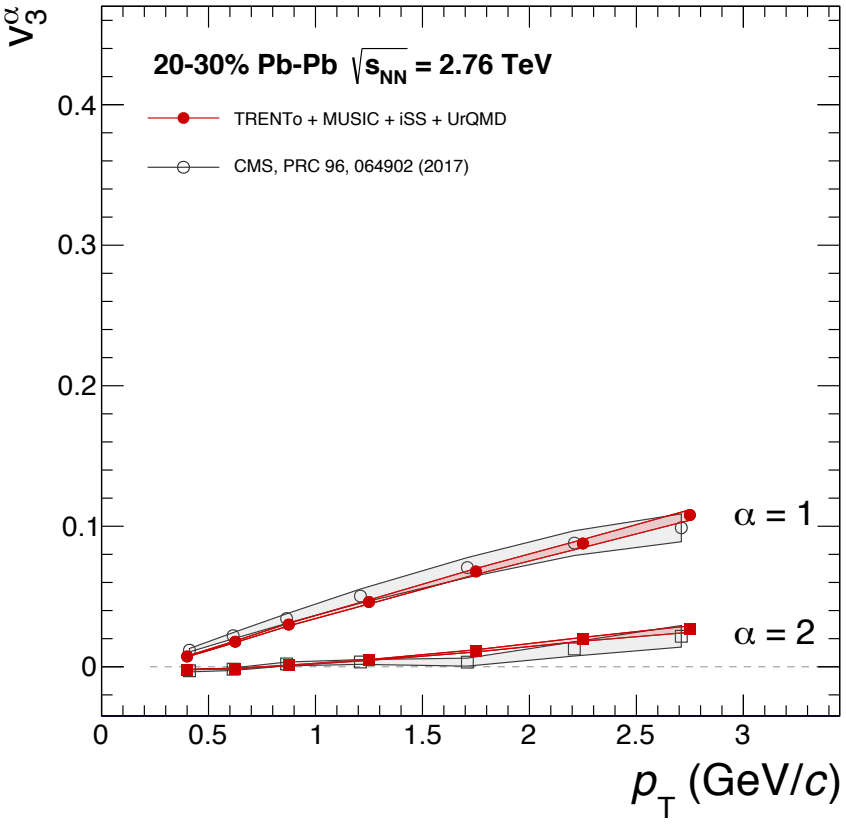




Model describes data within uncertainties for $\alpha = 1, 2$.

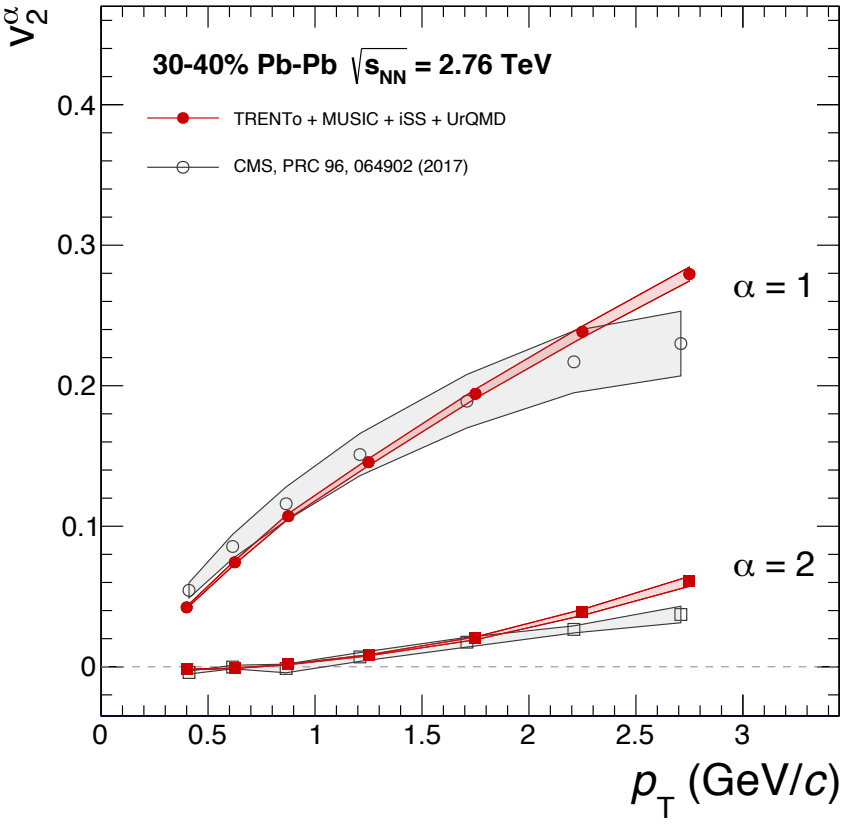
PCA for 20-30% Pb-Pb 2.76 TeV

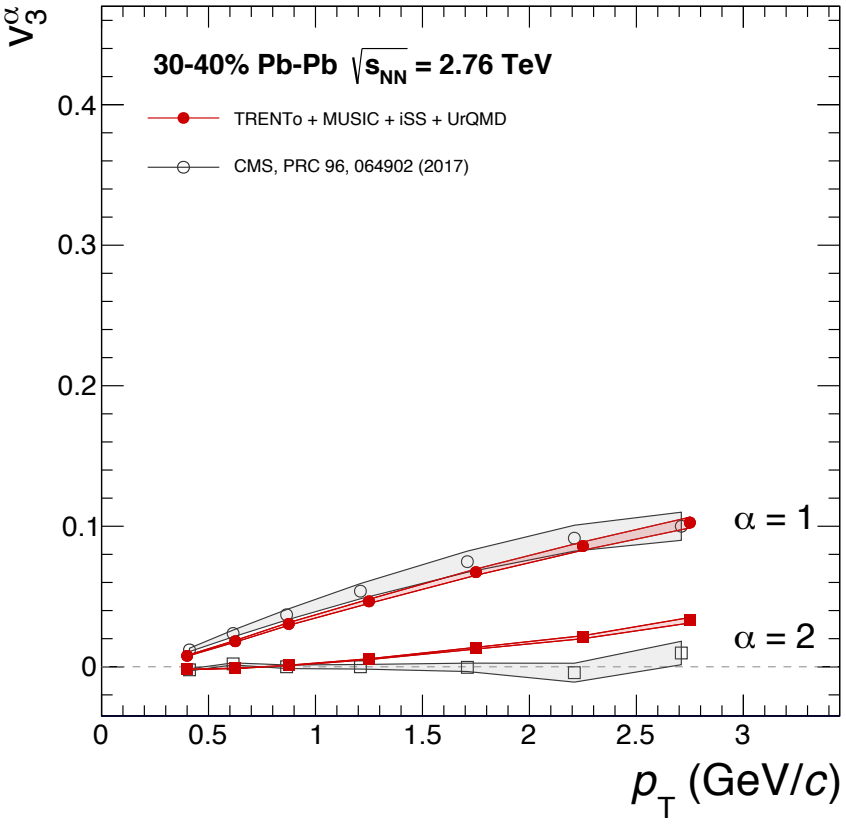




Model describes data within uncertainties for $\alpha = 1, 2$.

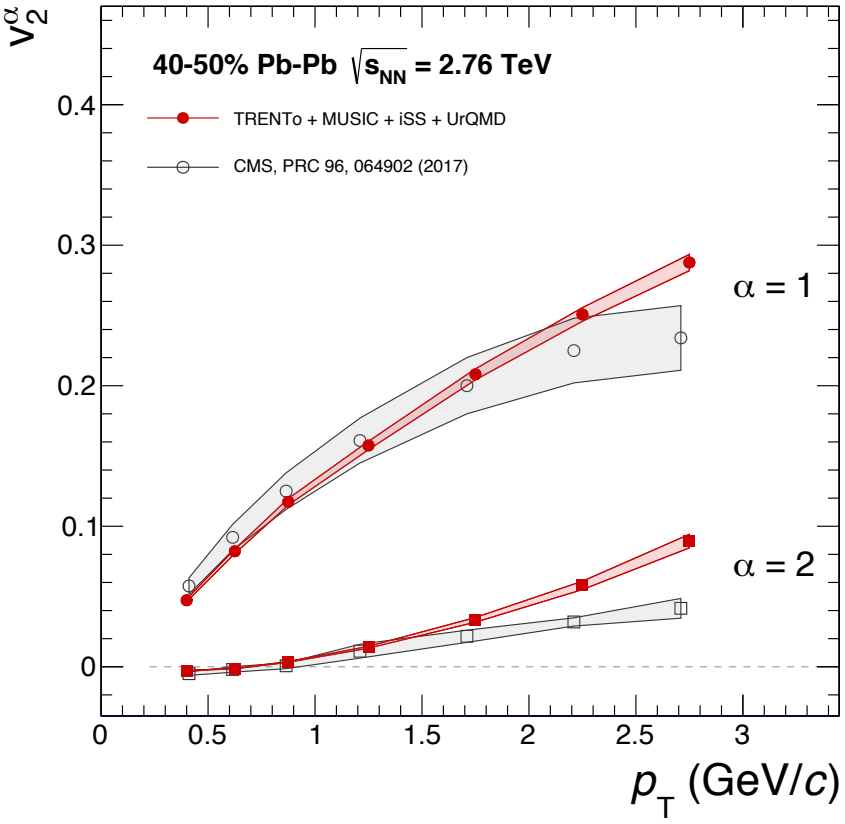
PCA for 30-40% Pb-Pb 2.76 TeV

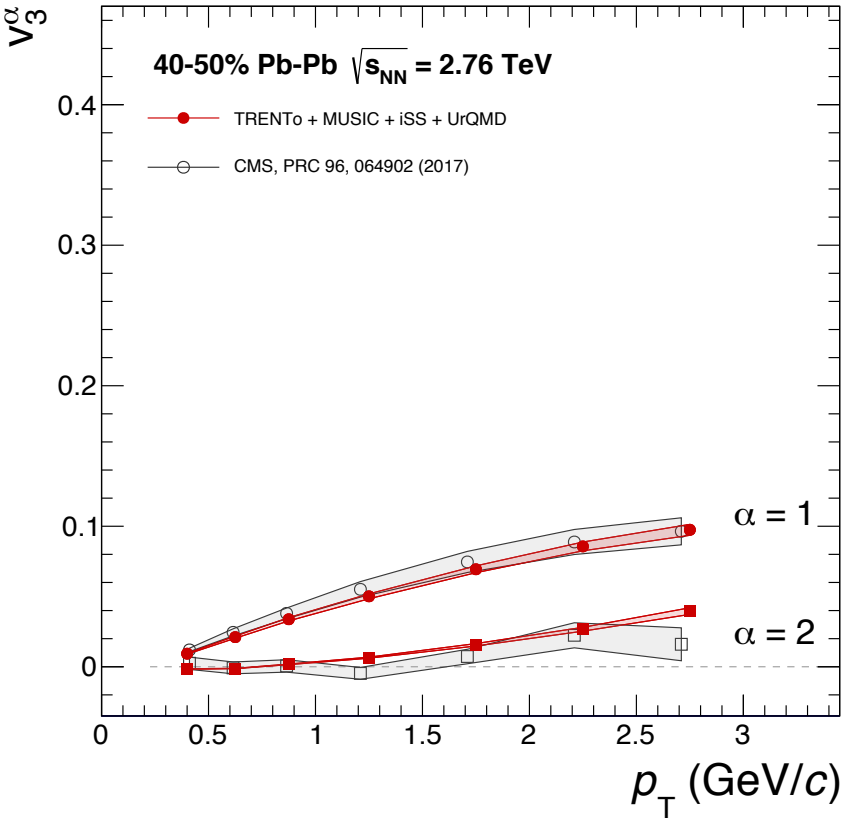




Model describes data within uncertainties for $\alpha = 1, 2$.
…but deviations appear for semi-central collisions at high p_T.

PCA for 40-50% Pb-Pb 2.76 TeV

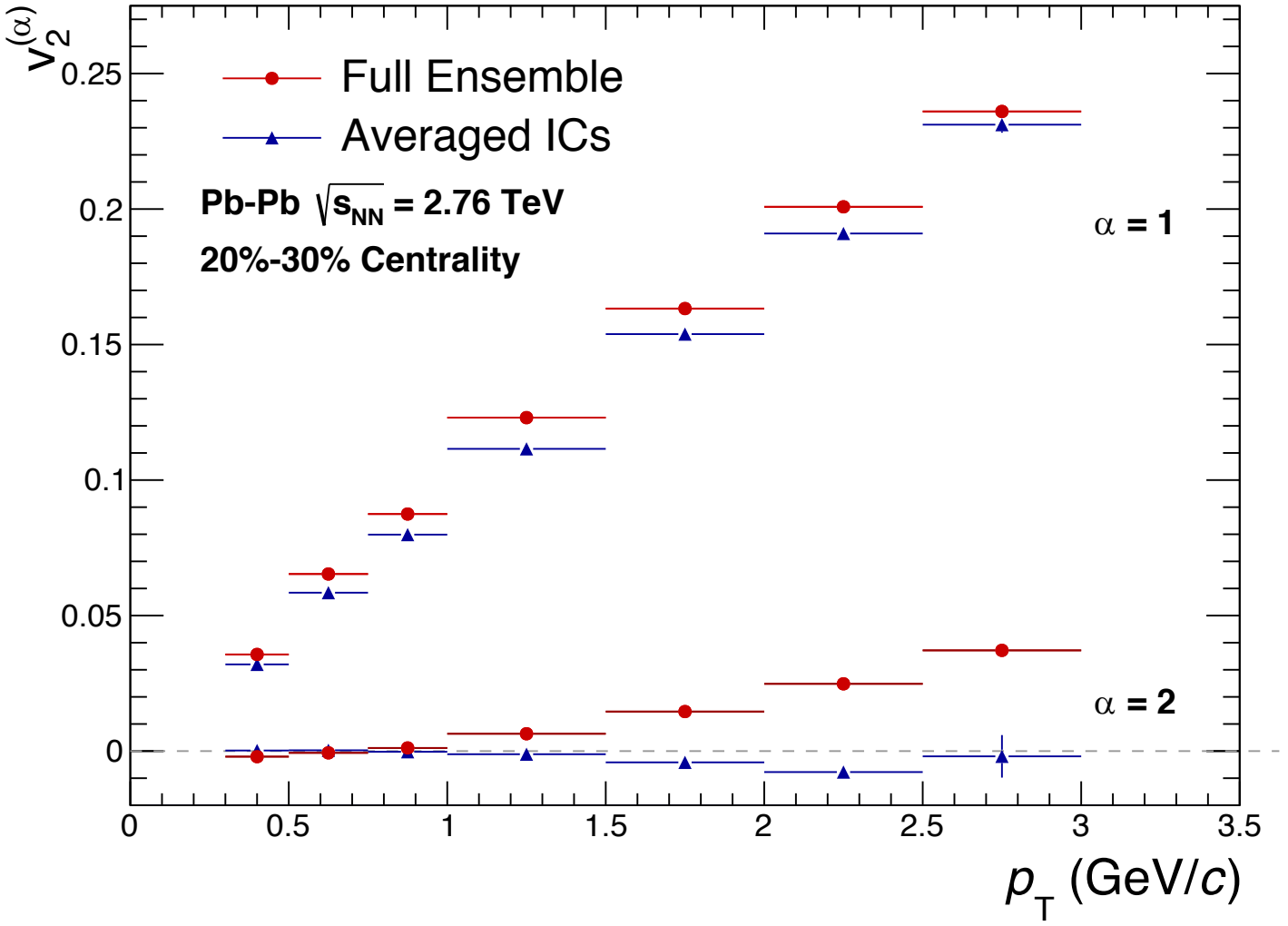




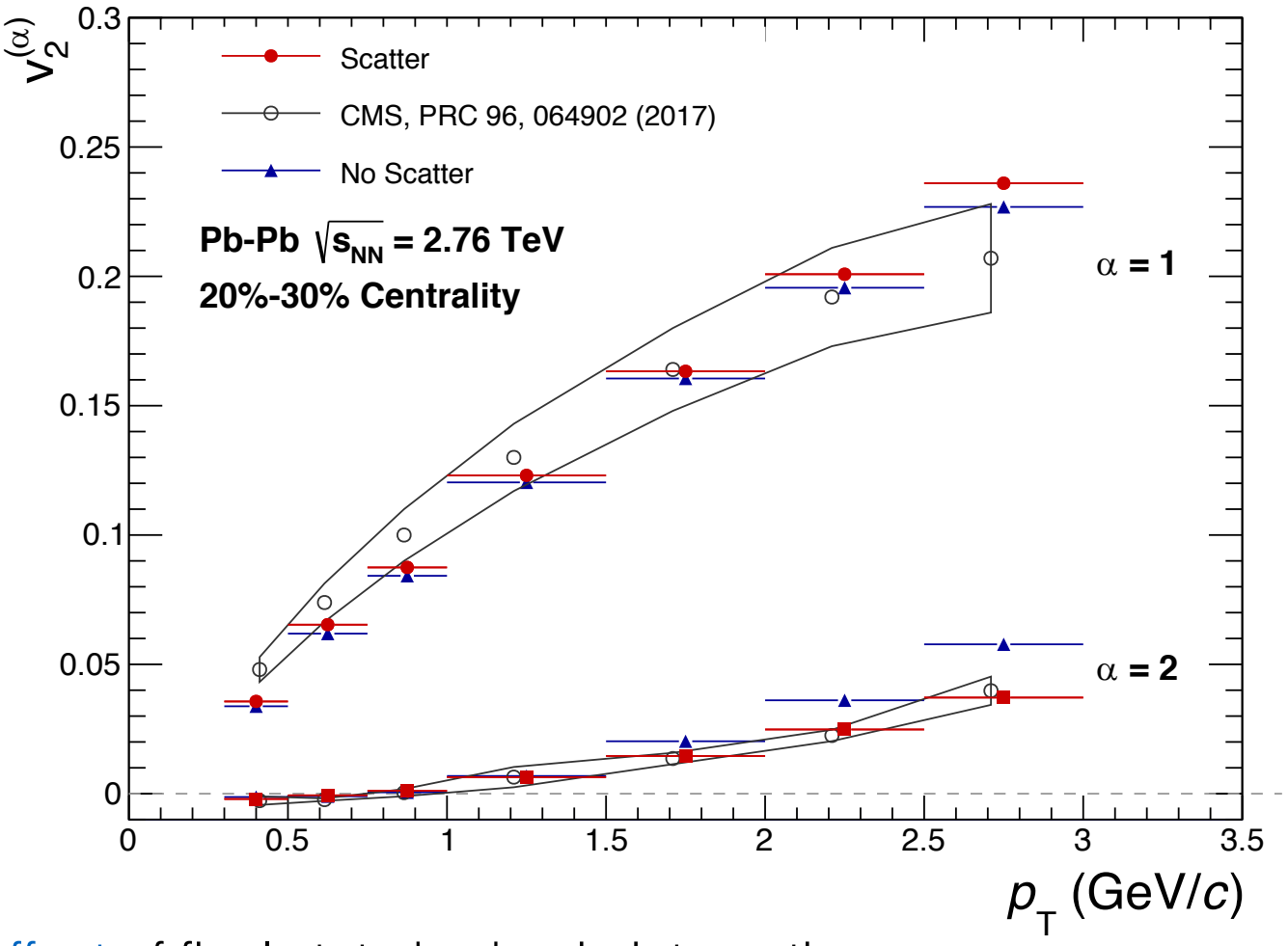
Model describes data within uncertainties for $\alpha = 1, 2$.
…but deviations appear for semi-central collisions at high p_T.

Still need to check what happens with KoMPost.

Effect of IC fluctuations

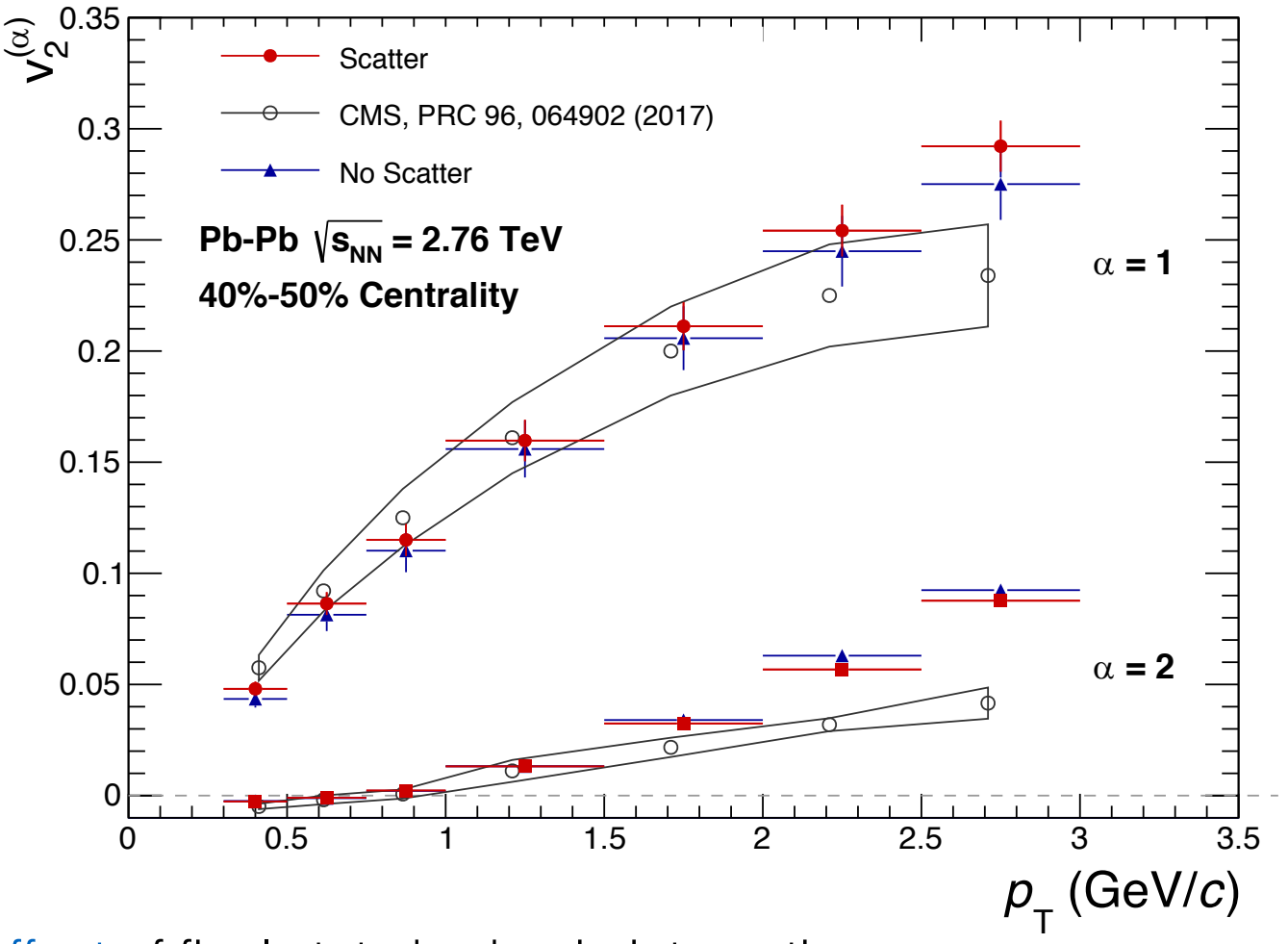


Effect of Hadronic interactions



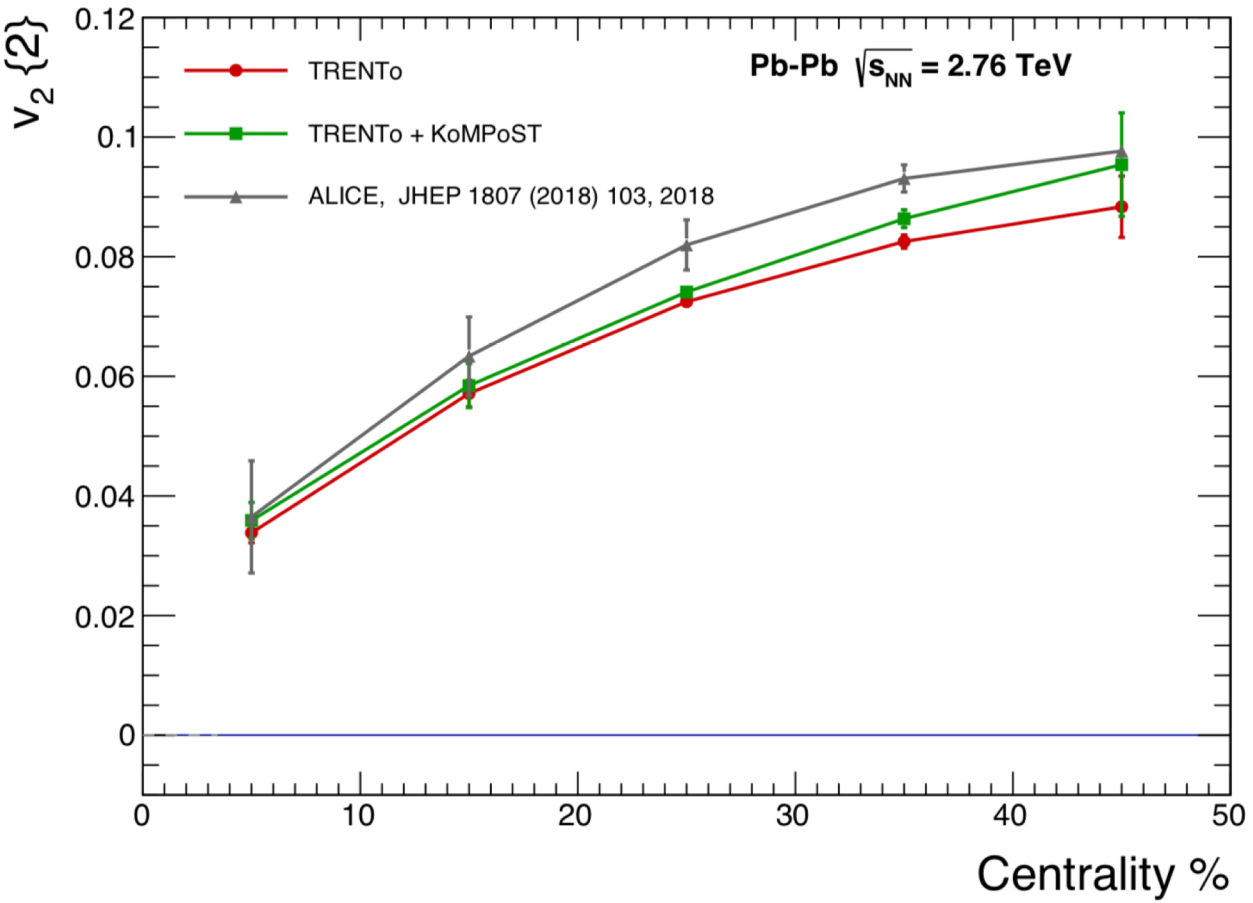
Small effect of final state hadronic interactions.

Effect of Hadronic interactions



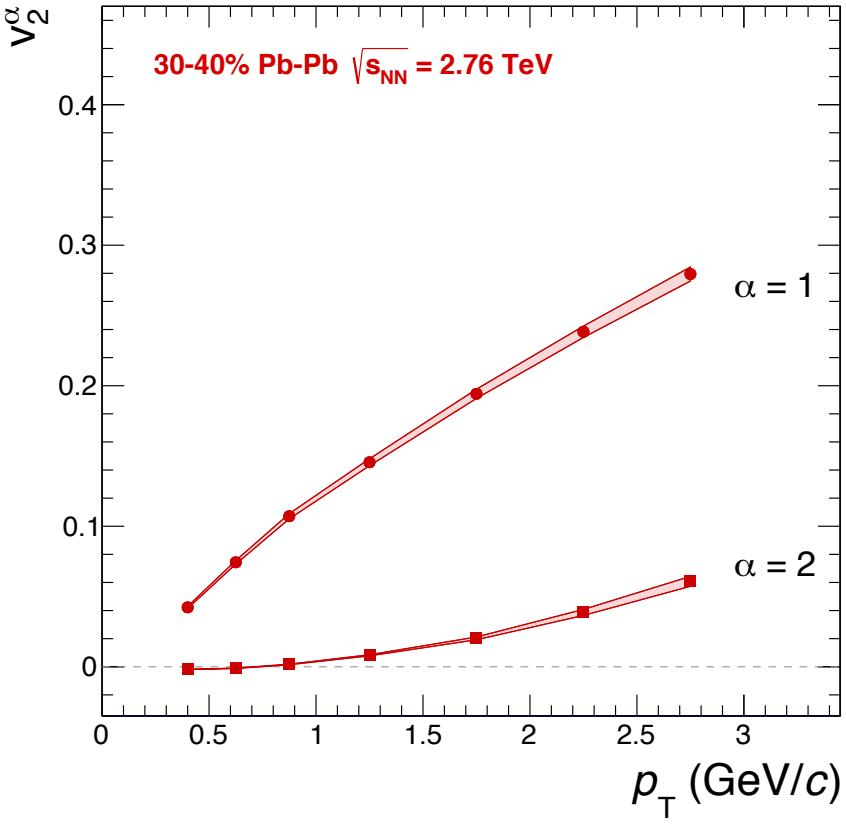
Small effect of final state hadronic interactions.

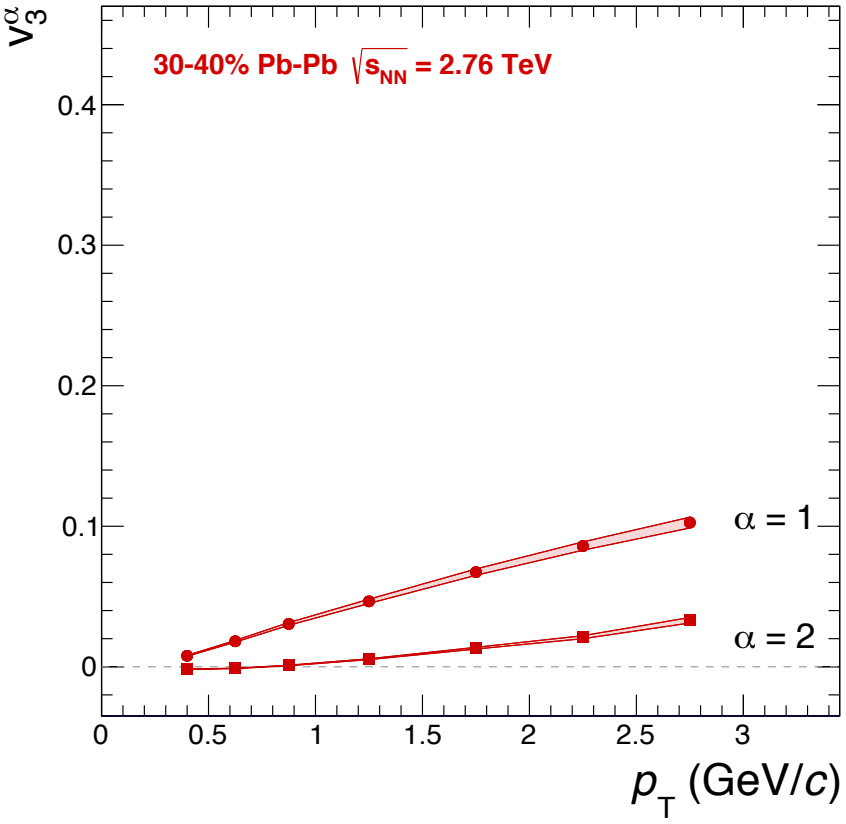
Effect of pre-equilibrium dynamics



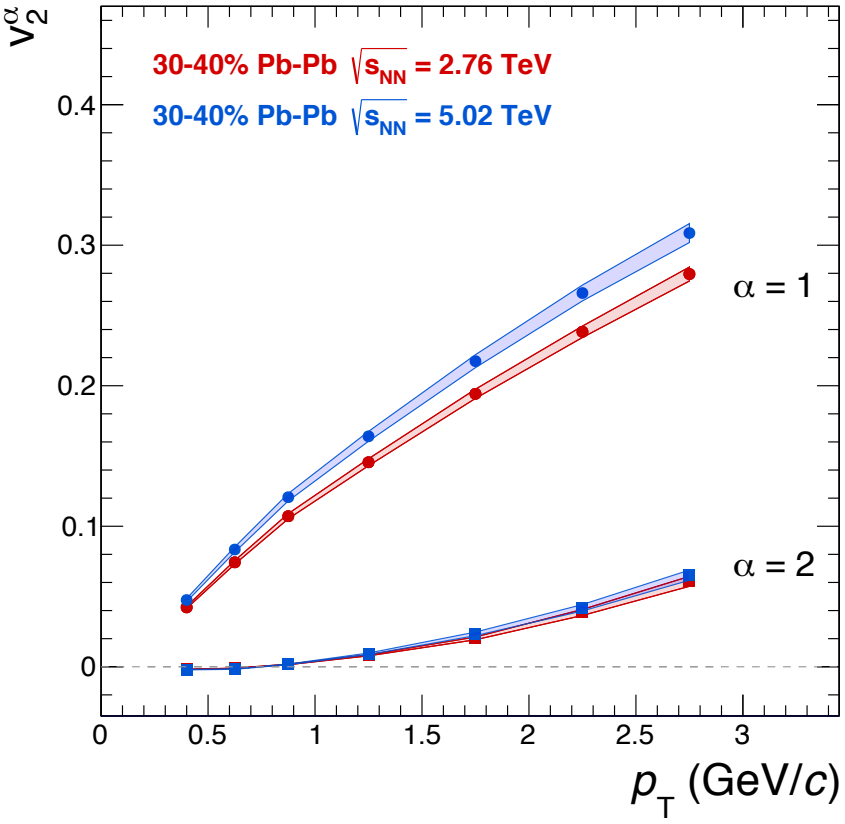
Slight increase in integrated flow with pre-equilibrium dynamics.

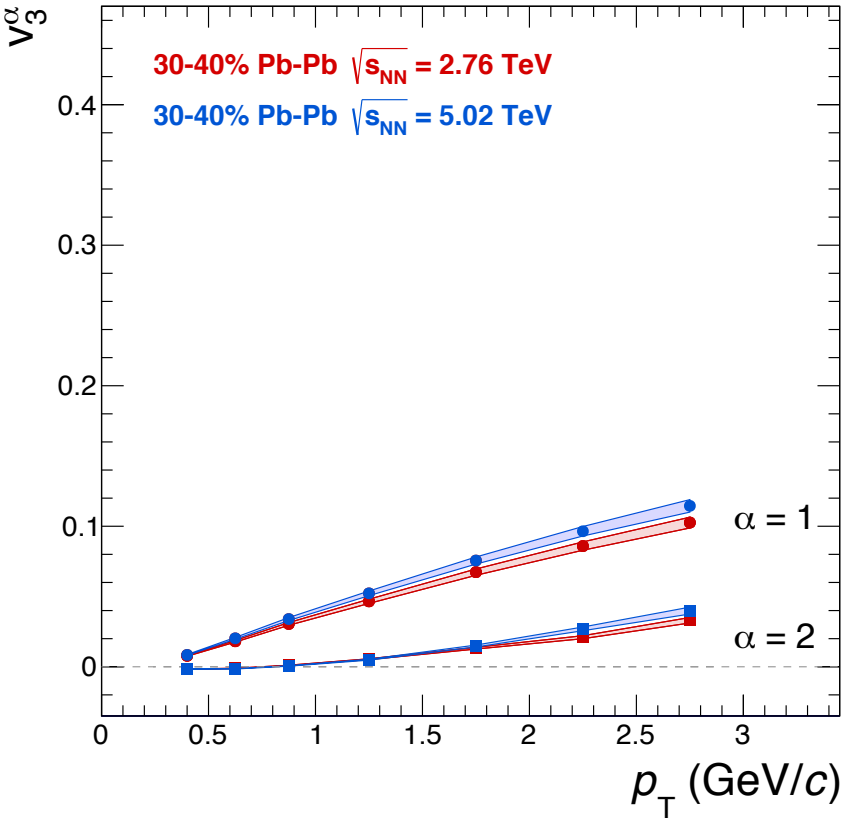
Energy dependence of PCA results





Energy dependence of PCA results

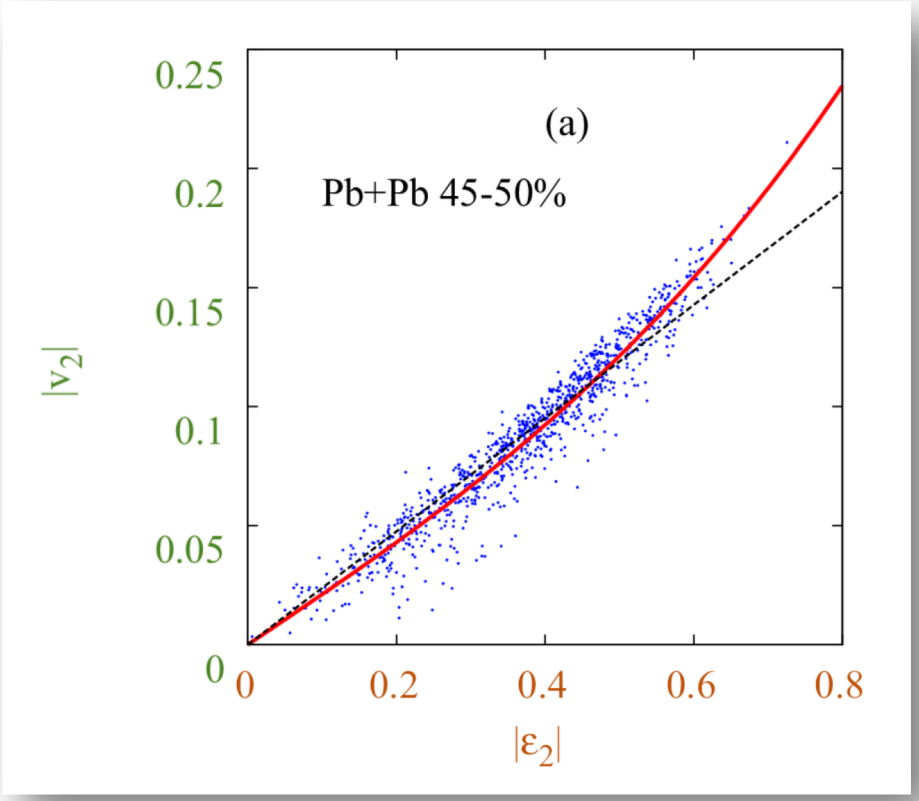




Weak energy dependence: $v_n^{(\alpha)}$ at most 10% larger.

Correlation between IC with final particles observable

PRC **93**, 014909 (2016)



$$v_n(p) = f(\varepsilon) + \delta_n \approx \underbrace{k_2 \varepsilon_2}_{n=2}$$

Dotted black line:

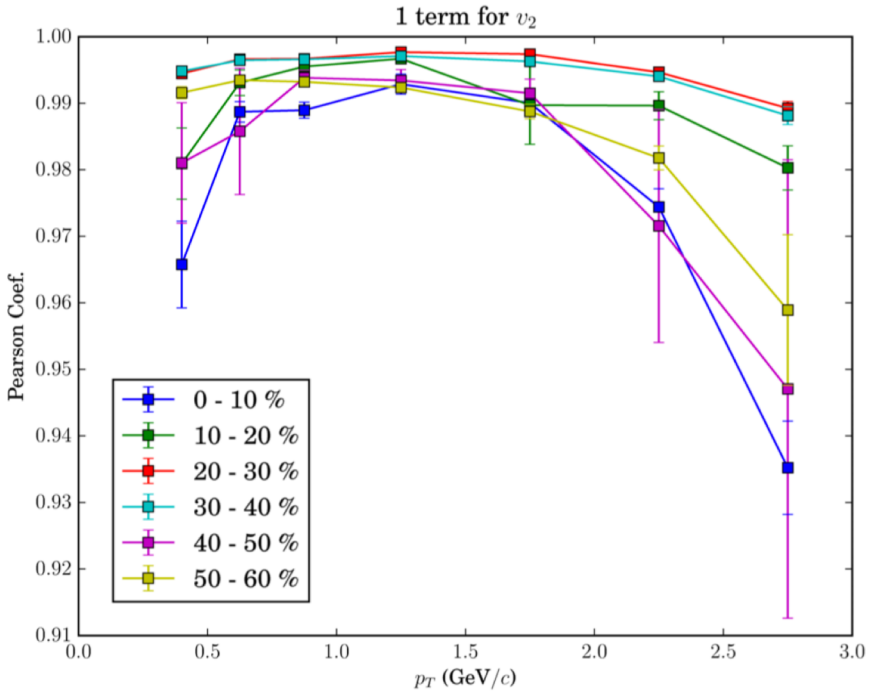
$$f(\varepsilon_n) = \kappa_n \varepsilon_n$$

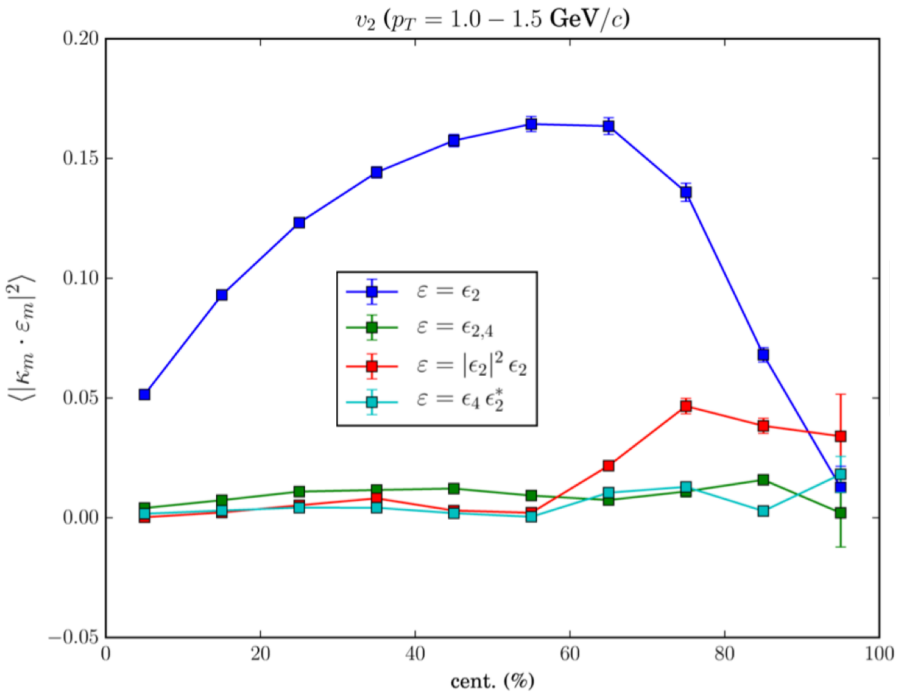
Solid red line:

$$f(\varepsilon_n) = \kappa_n \varepsilon_n + \kappa_n' |\varepsilon_n|^2 \varepsilon_n$$

ε_m: initial eccentricities (calculated from IC)

Correlation between IC with final particles observable





- p_T dependence of mapping allows for investigating dynamics.
- Higher order terms becomes more important in peripheral collisions.

Summary

- We have a working simulation chain that uses state of the art models for the different parts of a Heavy Ion collision, and allows for analysis different observables from final particles.
- Our hybrid model describes CMS data for the PCA of flow well in central Pb-Pb events at 2.76 TeV and a small (~10%) increase in the PCA results for 5.02 TeV.
- Lots of work in progress and many interesting things to be tested.

We are looking for a postdoctoral researcher interested on this subject to work with our group!!!!